Nichols & Doerr

The History, Construction, & Design

of Caisson Foundations in Chicago

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THE HISTORY, CONSTRUCTION, AND DESIGN OF CAISSON FOUNDATIONS IN CHICAGO

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

RALPH ULINE NICHOLS AND HAROLD FRANCIS DOERR

ENTITLED THE HISTORY, CONSTRUCTION, AND DESIGN OF CAISSON FOUNDATIONS IN CHICAGO.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN ARCHITECTURAL ENGINEERING.

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THE HISTORY, CONSTRUCTION, AND DESIGN OF CAISSON FOUNDATIONS IN CHICAGO.

With the rapid development, in late years, of the large cities of the World, and especially of the United States together with modern improvements in fundamental details of construction, the term caisson has come to include several types comprising a large subject. The caisson has been defined as a pier of masonry or metal extending down to a firm foundation for the support of heavy bridges and buildings. Caissons are now used extensively for foundations of tall structures and differ in several respects from those used in bridges. There are two types employed, namely the closed or pressure caisson, and the open caisson. The closed type is always used in soils which are either wet, soft and muddy, or those containing strata of quicksand. Here the tendency of the water or soil to fill up the caisson is overcome by a greater air pressure maintained within the steel working chamber. Where the soil is fairly firm and free from moisture the open caisson can be used. It is the object of this paper to treat only of the open type of caisson as employed in the tall buildings of Chicago.

HISTORY.

Never before in history has the demand for heavy foundations been so great as it is at the present time. Great as were the strides of the Romans in unprecedented engineering works, they never reached the point in building construction where the continuous stepped foundation did not suffice.

Modern invention and the widespread use of steel have made it necessary for Architect and Engineer to seek anew solution for the foundation. Various types have been developed, the isolated pier with its spread foundation, the steel grillage and the pile foundation. The erection of skyscrapers has become so general in the modern metropolis that a new and firmer foundation had to be sought. The soil of Chicago might hold a few tall buildings satisfactorily on spread foundations within the loop, but when enormous weights are brought to bear on the soil uniformly, the problem becomes a serious one.

The soil on which Chicago is built consists of loam and made ground down to datum about 14'-0" below sidewalk grade, then comes a layer of hard, stiff blue clay 6 to 12' feet thick, below this the clay while generally of the same character as the hard stratum above becomes softer, and remains soft to a depth of from 60 to 70 feet below sidewalk grade. This soft layer, as a general thing, only differs from the hard layer above in the amount of water it contains, and the buildings in their settlement squeeze out this water, thus increasing the thickness of the hard layer.

Before the great fire in Chicago in 1874 , which was as great a benefit to the city as it was a disaster, the grade level was but a few feet above the Chicago River and consequently the city was very unhealthy. That the grade had to be raised was well recognized by engineers and builders. It was for this purpose that the large amount of debris caused by the conflagration was used, raising the grade fully ten feet, or about

fourteen feet above the river.

Following the fire Chicago entered upon a period of reconstruction and further development. The great strides in building progress were made possible only by the utter demolition of the many wooden buildings which stood in the business district. The new buildings were of masonry and were built larger than the old ones which they replaced. The problem of designing the footings soon became an all important one and many solutions were offered and attempted causing success or failure as they were rational or absurd.

In attempting to secure sufficient bearing on the upper crust of clay, on one or two occasions attempts were made to solidify the soil by a heavy bed of concrete, which it was assumed would equalize the pressure and prevent any settlement. This plan was tried for the foundations of the post office and customs house, a large building on the south side of the city erected under the supervision of a government architect. A bed of concrete, about three feet in thickness, was spread over the entire area to be covered by the building, and upon this the walls and foundations were started exactly as if they were resting on a bed of solid rock. The result was most disastrous. There was not a wall in the entire building which did not crack through and through , nor was there a string course or a cornice which could show anything like a horizontal line. The building has been torn down but it used to be nicknamed "The ruin" and very appropriately.

Mr. Frederick Baumann was one of the first Architects to

thoroughly appreciate the problems involved in Chicago Foundations and to devise a scheme for building upon such poor earth. The plan used by him has since come into general use in the construction of all the larger buildings. His idea involved no new principles by any means : it is simply the old Gothic idea of building with isolated piers so that all the loads and weights are concentrated at points, and the foundations under these arranged so that the pressure on the earth shall be exactly equal in all portions.

It was essential that the footing be made as shallow as possible since it was inadvisable to dig into the upper crust of clay and basements were demanding head room for operating machinery. To this end the railroad beam grillage imbedded in concrete was employed. With these materials it was possible to spread 15'-0" in a depth of 19" . The loads were a source of difference. In office buildings the live load was theoretically taken at 150 lbs. per square foot when an actual determination of the live load showed no more than 25 lbs. per square foot. Pressure on the soils was taken at from 1-1/2 to 2-1/4 tons per square foot and rigidity given to the walls by tieing them together by rods in the floors.

It was no uncommon thing for architects to draw two grade lines, one showing the original sidewalk level, and a second one showing the level to which the building would settle. When calculated with care this could be done to great accuracy as shown by Burnam & Root on the Rookery Building, and by Cobb& Frost in the Opera House Building. In the last mentioned

building there is a long corridor on the ground floor which today stands level over its entire length, bearing witness to the exceedingly careful design of the architects, who cleverly proportioned the footings for equal settlements.

There were, however, many failures which indicate that the successful job was rather exceptional.

When the foundations of the new Post Office were put in, extremely hard clay, that had to be cut out with draw knives and thrown into the wagons with pitchforks, was found down to a depth of 35 or 36 feet, although when buildings near it were built, soft clay was found at about 20 ft. below sidewalk grade. This is but one example of the great variation in the nature of the soil and shows how carefully spread foundations must be designed in each particular case.

It was found early in the use of spread footings that it was not advisable to dig into the hard stratum at all. The foundations were placed upon this hard stratum wherever it was found, and this in some cases only allowed a clear height in the basement of 7-1/2 or 8 feet. Before the Masonic Temple was built the soil was tested by supporting a tank on a plate having an area of two square feet. This tank was gradually filled with water and the final load was 5,650 lbs. per square foot. Two tests were made, each lasting 100 hours. In one case the plate rested directly on the top of the hard clay. In the second test the plate was placed at the bottom of an excavation in the hard clay, 2'-4" deep. The total settlement in test No. 1 was 1-13/16", and in No. 2, 4-1/8".

Below this clay comes a very hard , compact clay, frequently containing boulders of various sizes, some of them being five or six feet in diameter. This clay continues down to either the rock or a layer of sand and gravel of varying thickness which occasionally overlies the rock. Rock is found in the down town district at about 100' below street grade. In an artesian well sunk at the Chicago & Northwestern Office Building this limestone rock started at about 100' below datum and continued down to -434', then came a layer of blue shale 53' thick, then 350' of limestone, then 160' of soft white sandstone, then 300' of limestone and finally at -1400' a white sandstone was found which contained water in sufficient quantity rising to within 100' of the surface. The old masonry foundations of the four to six story buildings erected after the fire were, of course, spread foundations, and their load on the clay ran from 8,000 to 15,000 lbs. per square foot. There must have been great settlements, but with the streets varying so much in grade as they did, and with the masonry buildings it did not make much difference how much they settled. However, as the heights of the buildings increased and more room in the basements for mechanical plants became a necessity, it was found that some other kind of foundation was required, and the spread footings made of layers of beams imbedded in concrete naturally followed. The settlement of buildings supported upon these spread foundations was considerable, ranging from 8" to as much as 30". This settlement is anticipated when construction is begun by raising the level of the bottom of the footing by the amount it

is thought the building will settle. This difficulty might have been overcome by placing jacks between the footing and the column and screwing them up as the building settled thus keeping the building at a certain level. After a period of six months or until the greatest settlement had taken place, these jacks could be concreted in. In the construction as actually used it was necessary to build the sidewalks at first so that they sloped up to the first floor level. As the building settled the sidewalks approached their proper pitch. The foundations of the Great Northern theatre were built 9" above the desired grade to allow for settlement.

It has also been found that the tall buildings with spread foundations do not stop settling. This continual settlement is caused by the wind tending to reduce the pressure on the soil on the windward side and increasing it on the leeward side. Some of the tallest buildings erected twelve to fifteen years ago are still settling- very slightly it is true, but the movement is enough to be detected. Another fact noted is that all the tall steel buildings lean north and east. This is due to the fact that in the spring and summer, when the buildings are being erected, the prevailing winds are from the southwest, and as the greatest settlement occurs during erection, this constant pressure against the unfinished structures is sufficient to cause them to lean slightly.

The following incident will show how great is the initial settlement. In the Masonic Temple four of the main columns, near the lifts, carry heavy loads and have large footings, and

between them are two small columns which only carry the stairs. As these have much smaller footings than any others in the building, they were given a higher load per square foot. During the construction of the building the four columns had received the greater portion of their load when the erection of the stairs was begun, it was found at once that the connections on the stairs would not fit those on the columns, the latter being too high. Levels,taken to ascertain whether the small columns had been forced up, showed that they simply had not settled with the rest of the building. About 75 tons of pig iron was then loaded on both footings and allowed to remain for a week. Altho the load then amounted to 7,000 lbs. per square foot, twice the load on any other of the footings, the columns only settled about an inch, less than1/2 the desire amount, and so the connections had to be changed all the way up the stairs.

It was found early in the history of floating foundations that live load must not be considered when designing. The reason for this is that the foundations get the dead load immediately, but the live load does not come on until the building is finished and the greater part of the settlement has taken place.

One of the finest buildings in Chicago- a wholesale warehouse built nearly thirty years ago - was designed by a Boston Architect. He proportioned the footings for the same live and dead load he used in designing the columns. The result was that the outside walls, where the percentage of dead load was very great, settled at once, and the interior columns, where the percentage of live load predominated did not settle. If you go

into that building today you will see porters helping the regular truckmen to wheel their trucks up the hills caused by the curves in the floor.

The great settlement of buildings on these floating foundations and the necessity of increased basement height, owing to the increased use of water tube boilers and other improvements in the mechanical plant, led to the gradual abandonment of this style of foundation, notwithstanding its cheapness. But the chief reason for the change and the discarding of the spread footings was the building of the tunnel by the Illinois Tunnel Company. This was a remarkable piece of work. Thirty miles of this tunnel forty feet below street grade have been completed and the whole work was carried on without any tearing up of streets. Indeed, very few people in Chicago knew it was being built until it was practically completed. Shafts were sunk at the curb line, and the dirt was hoisted through these shafts and hauled away at night. This tunnel, together with the present agitation for subways for the street car lines render the concrete wells going to rock the only safe method of constructing foundations for high buildings in the business district.

Many of the buildings now being erected have basements going down to the level of the tunnel. A great deal of the clay excavated from the foundations of buildings is now taken out to disposal stations on the river through this tunnel, saving the teaming of it through the streets.

While most of the large warehouses along the river are on piles, yet a very large percentage of the buildings put up in

the last five or six years rest on concrete caissons. Concrete wells would be a better name as they are simply holes dug just as an ordinary well and filled with concrete.

The caisson foundation extending to bed rock will carry a load sufficiently heavy to accomodate any type of building which is likely to be built in Chicago for a good many years to come. The height of buildings under the new code has been limited to two hundred feet from sidewalk grade to cornice, and consequently the weight of the structures themselves is limited to a great extent. The present Illinois Tunnel is forty feet below the street and a new passenger tube below this would not extend under the base of the bed rock caisson, and therefore would not in any way weaken the foundation. Since caissons to hardpan are sunk to depths of from 80 to 100 feet, approximately, it is readily seen that there will be no difficulty experienced by way of settlement when boring the present tunnel or any other proposed subway.

As in all new things there were many difficulties met with in the practical application of the caisson in Chicago. The very first building in which this type of foundation was employed was the Stock Exchange Building on LaSalle and Washington Street. This building was erected in 1893 about the time of the Chicago World's Fair. Mr. Louis Sullivan was the Architect and William Sooysmith the contracting engineer. Both the Architect and Engineer were thought to have been afflicted with that same form of insanity which Fulton, Edison, and many other progressive genii were said to have had. The expense was great owing to

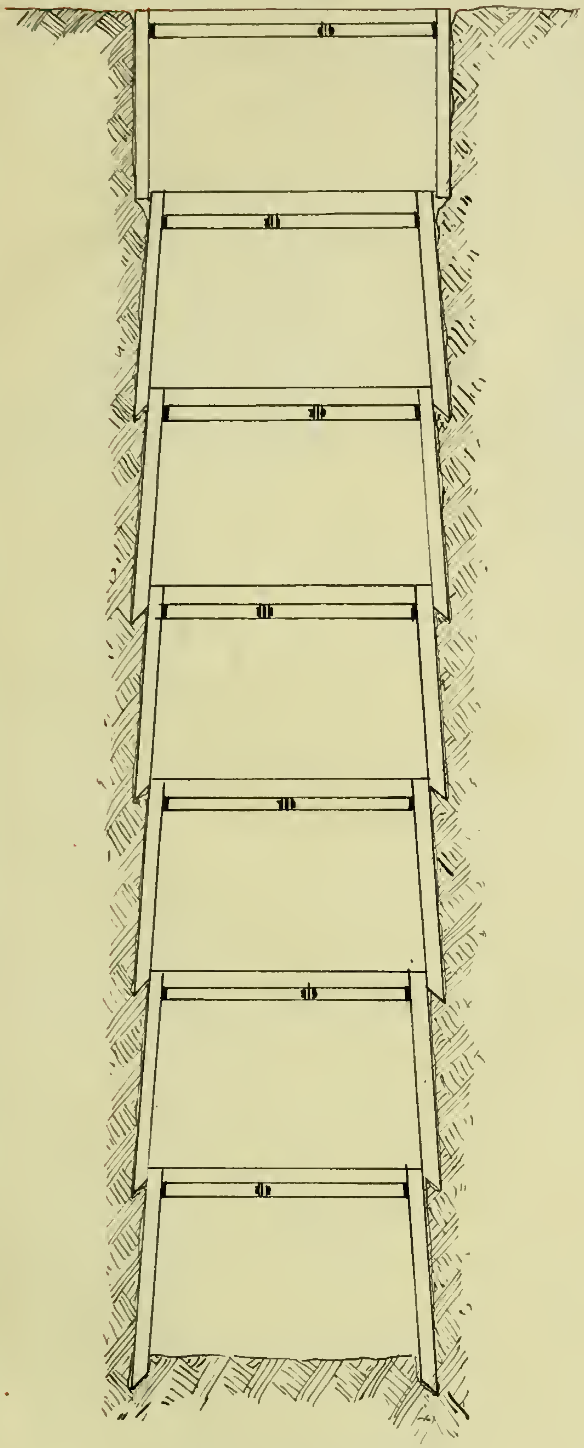
the inexperience of the builder. The equipment was new and the lagging was not sufficiently braced so that the caving in of the sides was not infrequent.

The greater part of the foundation of this building consists of piles which are about fifty feet long driven into the hard clay which overlies the rock. Next to the Herald building, however which adjoins it, wells were substituted, lest the shock of the pile driver close to its walls should cause settlement and cracks. Another reason given for the first venture in concrete wells was the fact that heavy trusses had to be supported which could not be carried on the ordinary pile foundation.

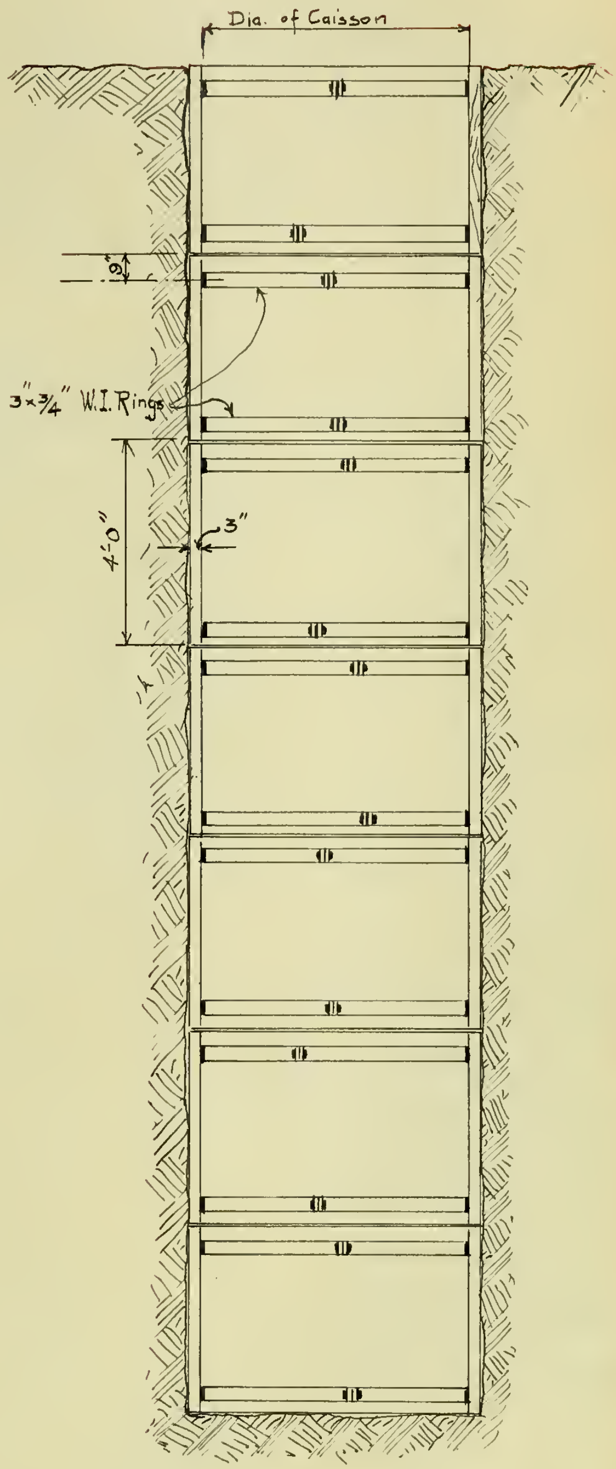
A short cylinder five feet in diameter made of steel plate was first sunk by hand, reaching below the footings of the Herald Building. Then around and inside the base of the cylinder sheet piles about five and one-half feet long were driven and held in place by a ring of steel inside their upper ends. The material inside the sheeting was excavated and a similar steel ring was placed inside their lower ends. By means of wedges, the lower ends of the sheeting were forced back into the soft clay until another course could be driven outside the lower ring. A sectional view of this lagging is illustrated under "The Old Method" on PLATE I. This operation was repeated until the excavation reached the hard clay about forty feet below the basement. In this material the excavation was continued without sheeting, in the form of a hollow truncated cone to a diameter of seven and one-half feet and the entire excavation was filled

PLATE I

METHODS OF PLACING LAGGING



Old Method



Present Method

with concrete. The wells are spaced about twelve feet on center. The loads upon them vary, some of them carrying about 200 tons.

Since the depth at which a soil having a sufficient bearing power to carry the desired load was not known, the caissons were dug until a soil which was deemed capable of carrying the weight was reached.

The work, although difficult and replete with risks , proved highly successful so that other architects adopted this type of foundation. The Merchant's Loan and Trust, and the Tribune Buildings of which Holabird & Roche were the Architects and George A.Fuller the contractor were the next buildings to be constructed on caissons. Caissons in the Tribune Building extend sixty feet below sidewalk grade to hardpan, and were put in at a cost of about $1.00 per cubic foot. In 1902 Burnam & Root put in the first belled type of caisson in the Field Building at State and Randolph Streets. Starting with a depth of about forty feet for the first caissons the wells were gradually dug deeper and deeper until the bottoms for the Field Building struck hardpan at ninety feet below the surface. It was not until 1903 ,however, that D.H.Burnam& Co. put in the first bed rock job in Chicago under the First National Bank Building. Since 1903 a good many buildings have used the bed rock type, although the hard pan jobs have been numerous especially on Michigan Ave, where the bed rock slopes rapidly away toward the Lake.

The use of steel cylinders was required for the wells under the Chicago Edison Company's Building at 84 Market Street to carry the shafts through quicksand. The Architects were Shepley,

Rutan, & Coolidge and Wells Bros. Company general Contractors of Chicago did the work. The dimensions of the site were about 75 X 90 feet and quicksand covered the entire area, being ten to twelve feet thick with its surface 100 feet below sidewalk grade. No clay nor hardpan was found below the quicksand but there was a layer of boulders varying from the size of cobble-stones to stones four and five feet in diameter overlying the rock. Twenty-four wells in all were sunk, eighteen being 6'-6" in diameter and six 8'-6" in diameter. The ordinary method of sinking wells was followed until the quicksand was reached. A steel cylinder was then put down made in three sections with vertical joints fitted with angle iron flanges for the connecting bolts. The excavation was at once started and as the sand was removed the cylinders settled by their own weight until they rested on the boulders. The boulders then had to be drilled and split. It was found hard to settle the cylinders after they had stood for several days and it was necessary to use jacks to force them down so that the bed rock could be cleaned and the concrete put in.

The Continental And Commercial National Bank Building is one of the best examples of present day caisson construction. One hundred and fifty wells from six to eleven feet in diameter were sunk to a depth of 105' to bed rock. The soil in this lot was of such a nature that it could be excavated and 5'-4" lagging used all the way down. It took two men about five days on an average to dig a seven foot well. A 1:2:4 mixture of concrete was used and a caisson was filled in eight hours.

The cost of the caissons complete, including excavating and concreting averaged about $14.00 per cubic yard. Two sets of I-beam grillage transfer the load from the base plate of the column to the granite concrete capping . The lower set of grillage beams consist of ten inch I-beams resting on wooden screeds which are imbedded in the concrete capping. The upper set consists of three 25" I-beams provided with stiffeners and gas pipe separators. These caissons are designed to carry a load of 29 tons per square foot. It was cutomary at first to remove the lagging as the concrete was poured, but modern practise leaves the lagging in place, it being considered cheaper to do so.

Thus it may be seen that Chicago has made great strides in the development of a suitable foundation for tall buildings under poor soil conditions. The caisson has proved very satisfactory and, although the first ones were used in a building in Kansas City, the credit for the development to its present state is due to Chicago. Much credit is due Louis Sullivan, William Sooysmith, D.H.Burnam, and Holabird & Roche for the solution of this great problem.

CONSTRUCTION.

After the old building has been wrecked the basement is excavated to a depth of from 15 to 18 feet below sidewalk grade, depending on the nature of the soil. Below this depth there is a stratum of soft blue clay, and usually a considerable amount of water which it is impossible to team on and necessitates very heavy planking. For that reason the basements are excavated to the above depth.

The hardpan type of caisson is so called because it bears on hardpan. In the loop district of Chicago this layer is between 70 and 85 feet below sidewalk grade. The first real step in the construction of caissons is the "laying out" by the engineer and the "topping." The caissons are laid out from a base line established from the surveyor's plat. It is very necessary that these be laid out accurately as on them depends the stability of the building.

"Topping" is the expression used to denote the placing of the first set of lagging. A sweep which will swing out to the exact center of the caisson is first set in place. This consists of two stakes driven about five feet apart and connected across the top with a 2" x 4" or 2" x 6", and the sweep proper, which is nailed to the connecting piece, is fixed so that it will swing out over the exact center of the well. A plumb bob is used on this sweep to keep the caisson centered correctly.

After placing the sweep the well is started and dug to a depth of 3'-6" and to a diameter equal to the diameter of the caisson according to plans plus six inches to allow for three

inches of lagging. The lagging is then placed around the well and held with a ring about 9" from the bottom. The lagging is then driven 3 or 4 inches in the clay and another ring placed nine inches from the top. The clay is then tamped around the outside to hold the lagging solid.

The rings used in this work are of wrought iron, forged in half circles with a 3" lug on each end. These lugs are bored and when the ring is put in place the halves are bolted together with 3" x 3/4" machine bolts. These halves are forged so that their outside diameter is equal to the diameter of the caisson. The size of the metal used varies with the size of the ring. The smallest rings, 4'-0" in diameter, are made from 3" x 3/4" material and the largest ones, 10'-6" and 11'-0", from 4" x 1" material. For the intermediate sizes 3" x 7/8", 4" x 3/4", or 4" x 7/8" material is used.

The lagging used is hard maple free from knots, and tongued and grooved. It comes in two general lengths, 4'-0" and 5'-4", in two general thicknesses, 2" and 3", and in 4", 5", and 6" widths.

The next step in construction is the "setting up". There are three general ways this may be done which are termed tower, surface, and street level construction. The first two are the most common, a drawing illustrating the tower method can be seen on plate No. III and the frontispiece illustrates the tower construction in use on the Continental and Commercial National Bank Building, Chicago, Illinois during the fall of 1912.

The tower consists of a platform of two inch material built

on timbers from ten to fifteen feet above the top of the well. A tripod made from 4"x 4" timbers is placed on this platform so that its apex will be directly over the center of the well and of a 2'-6" X 2'-6" hole in the floor of the platform. Two legs of the tripod are connected together by two 3" x 14" planks and a shaft run through the center of these with a nigger head large enough to take six turns of 1-1/4" line is placed on the inside, and an 18" or 24" sheave for the cable is placed on the outside. A hopper is sometimes placed on the front or at one side of the platform into which the excavated material is dumped and from which it is emptied into wagons which drive under the hoppers.

In surface setting up the platform is built directly on top of the top set of lagging and the tripod placed on this. This method is cheaper to construct in both labor and material, but it requires an additional handling of the dirt to load it into wagons or into cars.

In street level work a platform of timbers and three inch planking is built over the entire lot at street level and either surface or tower set up placed on this. When this is done the basement of the old building is not excavated until after the caissons are in. This also saves the horses as they do not have to pull the wagons out of the basement. This method , however, is not economical unless the contractor is in the wrecking business and consequently has a large amount of old timber and planking on hand.

The number of wells pulled on one set up varies from ten to

fifteen but sometimes run to as high as eighteen. The wells are cabled together with a 5/8" wire cable which passes around the sheave on each tripod and over the driving sheave of the hoist engine. The motive power is furnished by steam hoist engines, but electric hoists are frequently used to pull one or two wells which could not profitably be connected in the general setup.

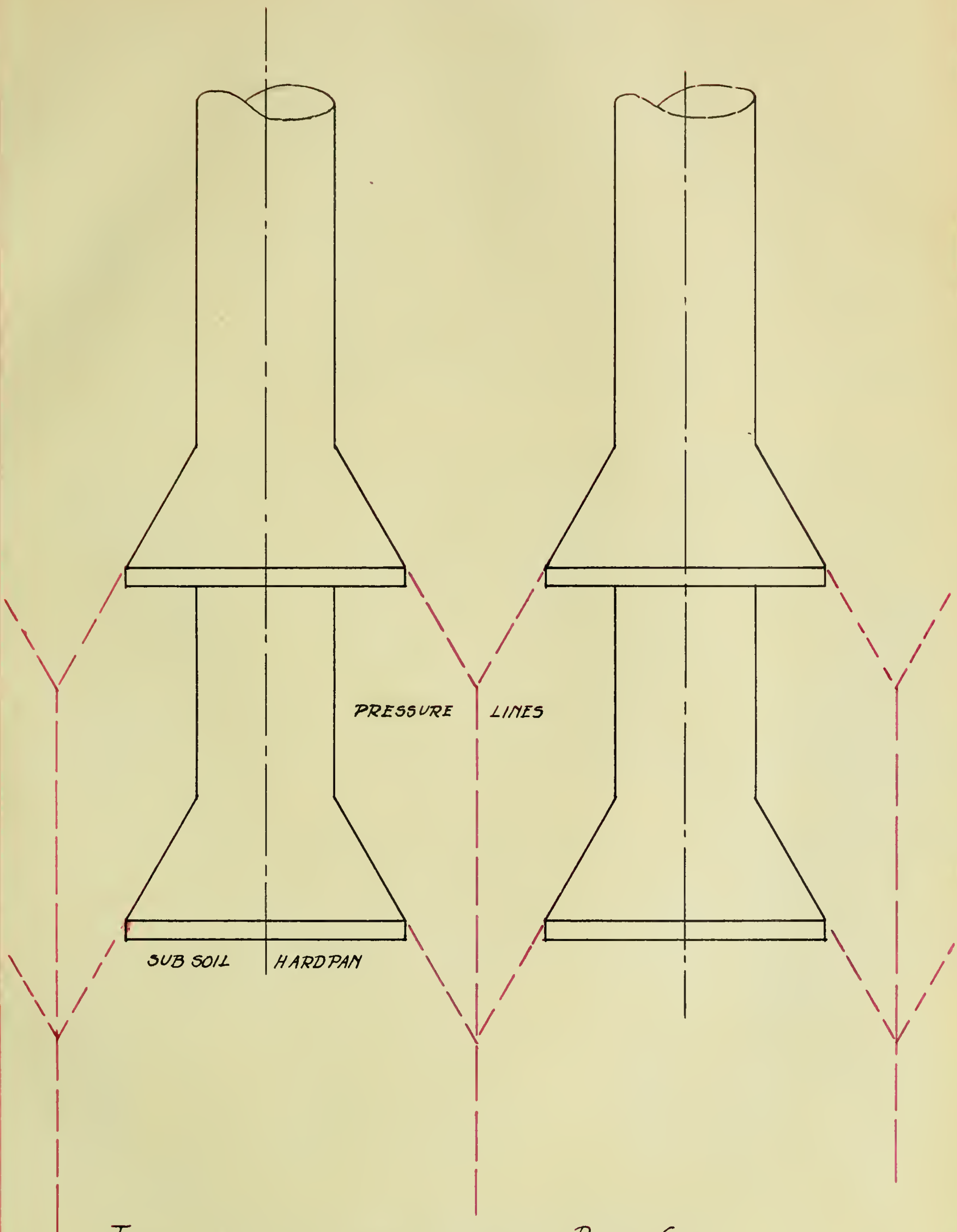
The actual digging is done by hand and there is a certain class of laborers that do this, they are nearly all "terriers", the low Irish, and are known as "diggers", because of the work they do. At the present time they receive 57-1/2¢ an hour for an eight hour day or 17-1/2¢ more than the common laborer.

The dirt excavated by these diggers is hoisted from the well in metal buckets of 5-1/2 cubic feet capacity. The man at the nigger head, or the "nigger head man" as he is commonly known, hoists the bucket with the aid of the nigger head. The dirt is dumped on the platform or in the hopper, as the case may be, and thence into wagons or cars and hauled away.

The digging is easy through the soft blue clay which extends to about 60 to 70 feet below sidewalk grade, from then on down to hardpan it is necessary to grub. Grubbing is loosening the clay with a grub which has a sharp blade 4" or 6" wide. The grub cannot be used in hardpan or where there are any stones.

The excavated earth is disposed of in either of two ways, by horse and wagon, or by car through the Illinois tunnel. If it is disposed of by teaming it is necessary to plank the basement so that the wagons can be drawn around and also to build a runway to pull the wagons out. The wagons must be pulled

PLATE II



THEORETICAL BASIS OF THE DESIGN OF THE BELLED CAISSON.

SCALE $\frac{1}{8}$ INCH = 1 FOOT.

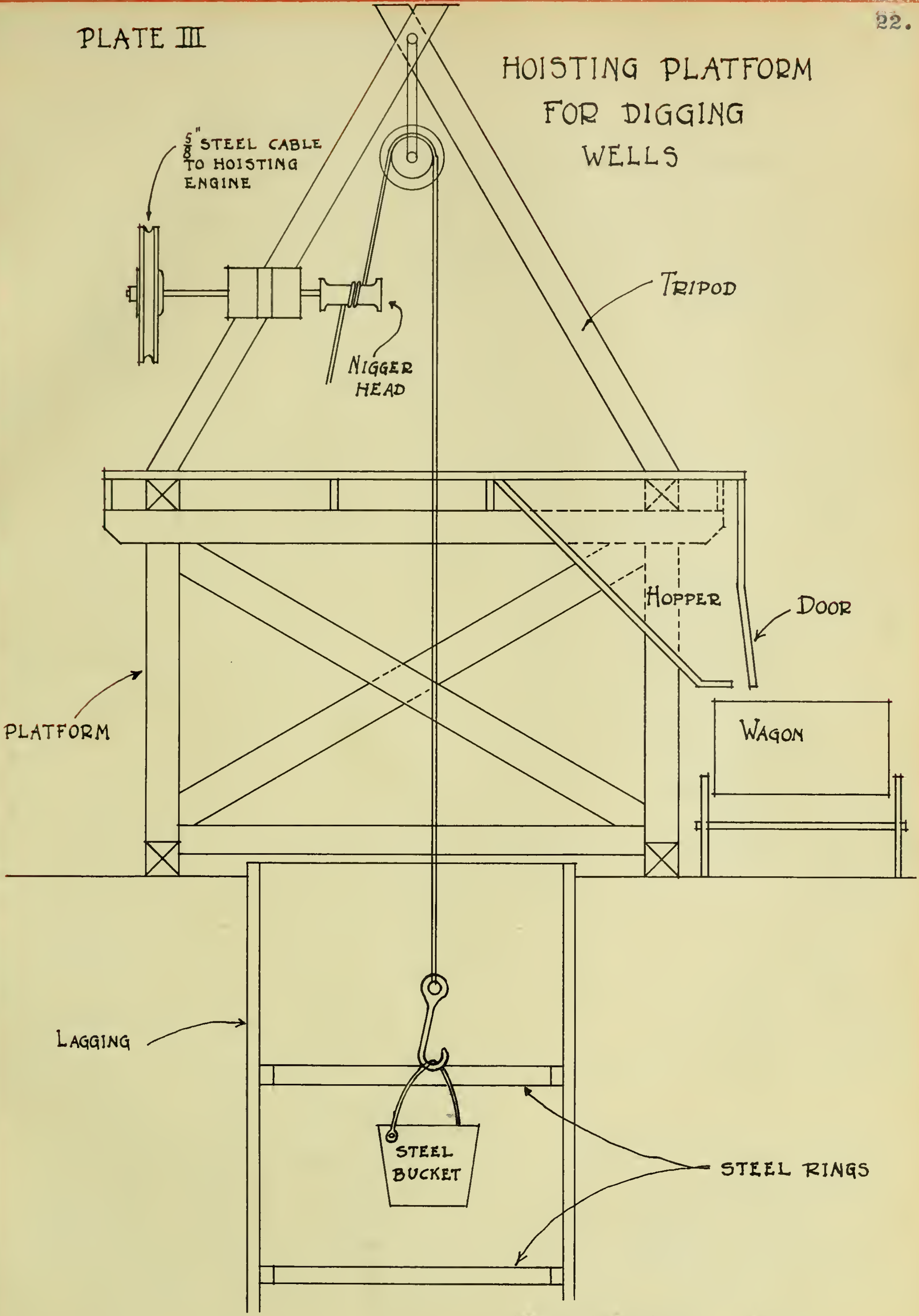
up this runway with either a snatch team, which is very hard on the horses, or by motive power. W. J. Newmann Co. have a device to accomplish this which is very saving. A narrow gauge track is laid down the center of the runway for a small but heavy car which is high enough to catch against the rear axle of a wagon. The wagons are pulled up so that the wheels straddle the tracks, the car is pulled up to the wagon by a cable and then it pulls the wagon up the incline. An electric hoist is used for motive power.

When the tunnel is used for disposal a narrow gauge track is laid around the wells in the "set-up". The earth is loaded into half yard cars which are pushed to the mouth of a 2'-6" metal tube, which leads to the tunnel, and the contents dumped into the cars in the tunnel. The excavated earth is finally disposed of in both cases by dumping it into scows at disposal stations along the river and then tugging it out into the lake and dumping it.

In digging hardpan caissons, they are first carried straight down to hardpan and lagged all the way. Plate I shows a section through the lagging illustrating the way it is placed in present day methods. When they are ready to concrete, the lower two sets of lagging are removed and the caisson belled out to its proper dimensions. These caissons may be built with a single or double bell as shown on Plate II, of which the single belled type is the more commonly used. All specifications for hardpan caissons say that they must be sealed immediately after belling out. Sealing is putting in enough concrete to cover the bottom of the

PLATE III

HOISTING PLATFORM FOR DIGGING WELLS



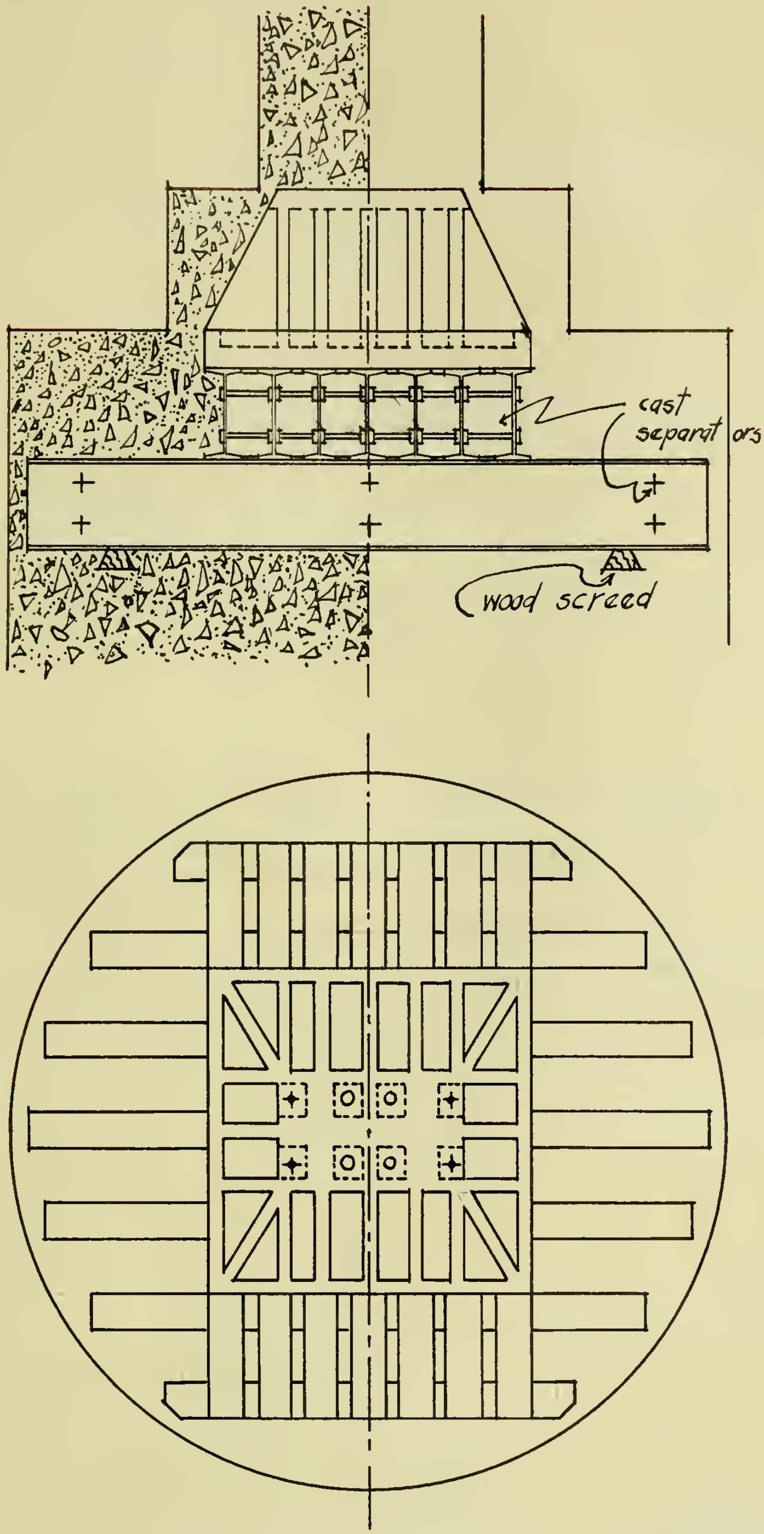
lowest set of lagging.

The concreting above the seal must be continuous so that there will be no joints. If for any reason the concreting should have to be stopped when the caisson is within twenty feet of completion, some sort of bond is necessary. A good method is to cross two half rings at right angles and to imbed all four ends in the concrete so that their centers will be two feet above the stopping point. Then, when the concreting is started again, the rings will serve as a bond. Two or three wells are concreted at one time; while concrete is being put in one, the men take the rings out of the other, two or three rings are taken out at a time, depending on the nature of the soil. In bad soil, where the pressure is great the rings are left in and the contractor is paid extra for all metal left in the well.

The matter of placing the concrete mixer so that the concreting may be done economically is a special problem for each job. Narrow gauge tracks are laid from the mixer around the wells to be concreted and shutes built at each well to receive the concrete from the half yard cars. Another method of getting the concrete from the mixer to the wells is by quarter yard hand carts. Most specifications call for a hopper and at least three lengths of pipe at the top of the well to direct the fall of the concrete straight downward.

From twelve to eighteen inches of granite concrete is put on each caisson just below the grillage so as to increase the bearing value, this concrete is made from granite screenings and cement. After the grillage is in place, the beams are grouted

PLATE IV

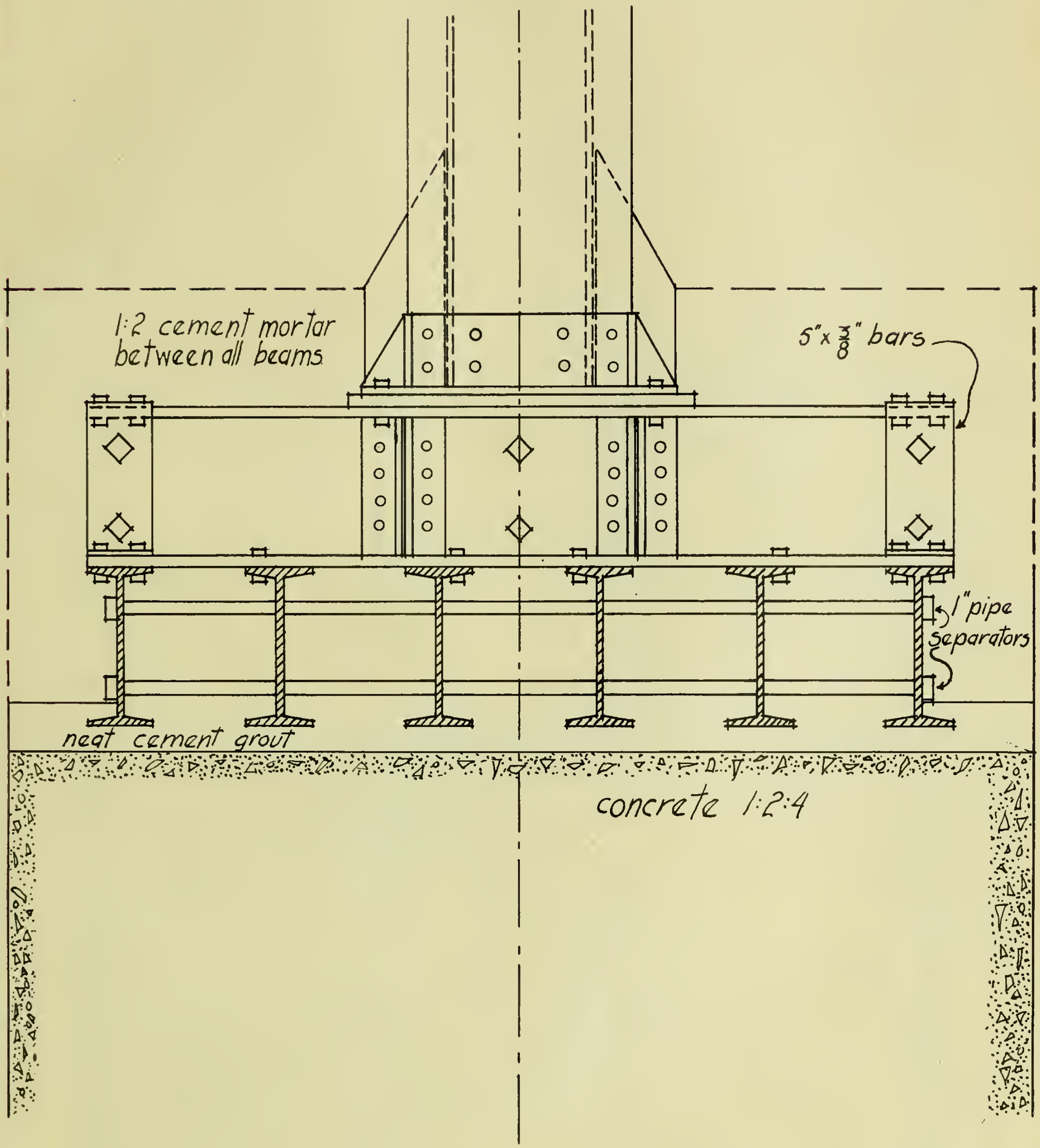


TYPICAL GRILLAGE DETAIL LYTTON BLDG.

SCALE $\frac{3}{8}'' = 1'-0''$

PLATE V

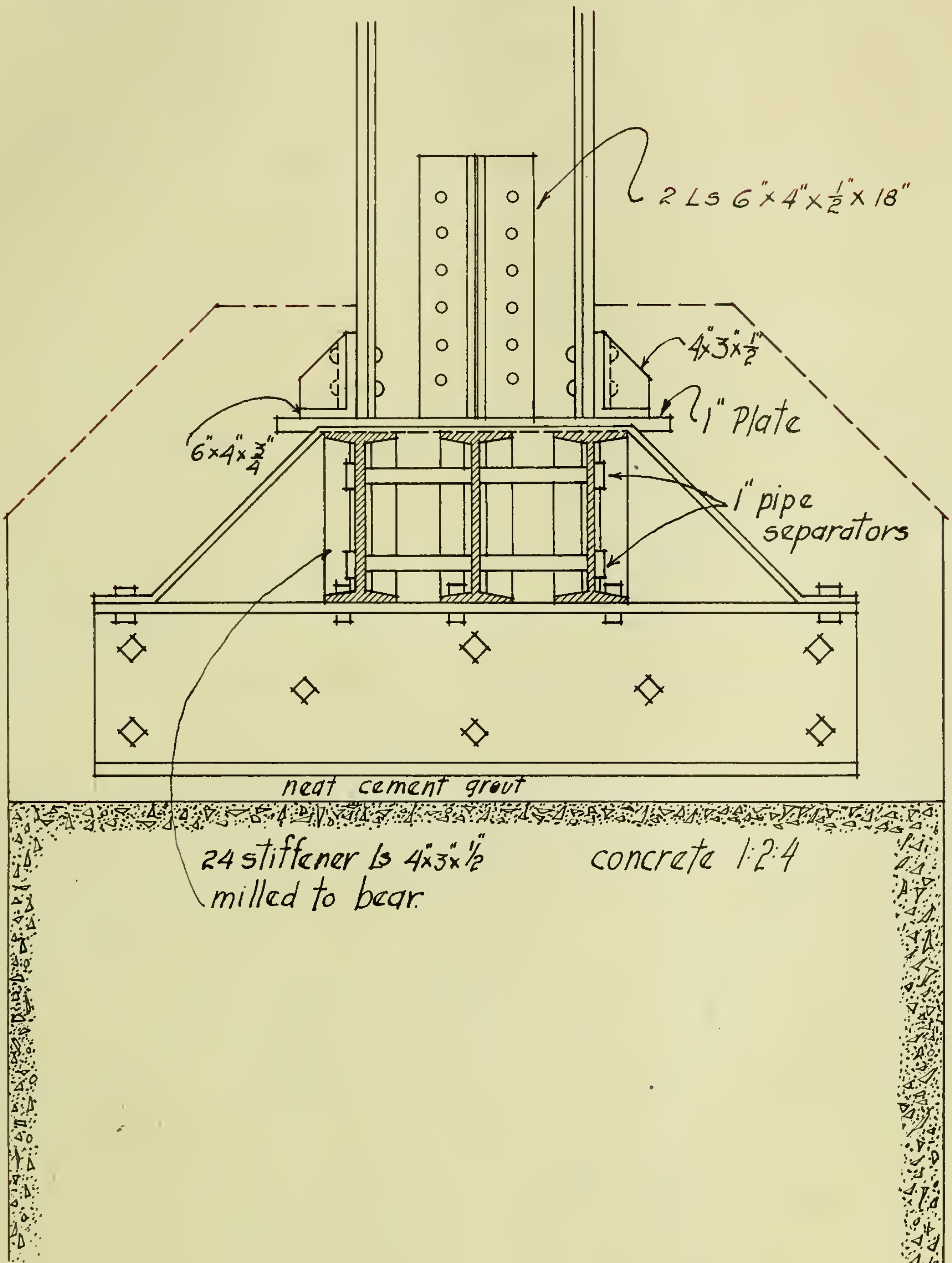
I-Beam Grillage Column Base



SCALE: 1 inch = 1 foot.

PLATE VI

I-BEAM GRILLAGE COLUMN BASE



SCALE 1 inch = 1 foot

in. Plates IV, V, and VI illustrate two types of grillage beams and bases grouted in.

When the caissons are belled out more than once as they were on the Peoples Gas Light and Coke Company Building, the method of digging and concreting is the same as described above except that the concreting is stopped at the level of the second bell, then the lagging is taken out and the second bell excavated. After this is done, the concreting is commenced again and the well finished in the usual way.

Bed rock caissons are those that extend to bed rock. The construction is analogous to that of hardpan caissons only it is necessary to dig through the hard pan and strata of clay and sand and gravel which are usually found underneath the hardpan. Bed rock caissons are never belled out and in elevation they have the appearance of a large cylinder of concrete.

The bedrock found under Chicago is a hard limestone and varies considerably in level, varying as much as ten feet in some lots. All rock bottoms must be tested and passed by the Architect's superintendent before the concreting is started. This test is to try the bottom all over with a railroad pick to see that there are no fissures and that the rock is hard. Some Architects require that every fourth or fifth well be drilled to a depth of eight feet to find out if the bottom is on solid rock. These caissons are concreted in a manner similar to that of the hardpan caissons.

The concrete used is either 1:2:4, 1:2-1/2:5, or 1:3:5 mix according to specifications, and the aggregate is either crushed

stone or gravel. Granite capping is a 1:1 mix.

The main difficulties which a contractor runs into in Chicago on this work are: heavy pressures due to adjacent buildings, very soft wet clay, the presence of water, and quicksand. If caissons are being put down on party lines and the adjacent buildings are on spread foundations it is necessary to put extra bracing on the inside of the well during construction. This is accomplished by means of half moons, drums, and jack screws. This bracing is put in on every set of lagging down to a depth of 55 feet below sidewalk grade when the soil as a rule become more solid. In a well where outside pressure is considered, three inch lagging is used down into the hard earth, and from that point on two inch stuff may be used. In other wells three inch lagging is used for three or four sets and then two inch stuff is used to the termination of the well.

Under some parts of the city a strata of very soft, wet clay is run into about fifty feet below sidewalk grade which will not hold up while digging the depth of one set of lagging. In that case it is necessary to drive the lagging through this strata; two widening sets of lagging are put in just above this strata, each of which increase the diameter of the well 6". Then another set of lagging is placed around the well inside of the lower widening set and driven with sledges ahead of the digging, two sets are usually driven thus bringing the well to its proper diameter.

Water is found to quite a considerable extent in work east of State Street and near the River. The presence of water is

overcome by the use of Nye Pumps, a pump in one well will usually take care of several wells around it. The fact that no water at all is found at some places is rather remarkable, for example, in some of the wells on the Continental and Commercial National Bank Building it was necessary to put some water in some of the wells so that the diggers could have wet shoveling.

There is no natural circulation of air in the wells and on some lots it becomes necessary to pipe compressed air down to the diggers. A few cases of black damp have been encountered when a well has stood idle for some time, on the Continental and Commercial National Bank Building a man was killed by black damp in a well that had stood idle for 38 hours while the shaft was being sunk through a stratum of sand.

Quicksand is not found in many places, the new Chicago and Northwestern Depot being the largest job in Chicago in which quicksand was encountered necessitating the use of compressed air. All specifications have a clause providing for an extra price in case quicksand is struck, this is for the protection of the contractor. Compressed air work which is very rare in Chicago is always handled by the people in New York who hold the patents on the air lock for sinking this type of shaft. It is not the object of this paper to go into this form of construction.

The construction of underpinning consists in removing in alternate sections a portion of the foundation and foundation bed of a structure and substituting other supporting material,

commonly providing a larger bearing area for the structure, for the purpose of reducing the load per square foot where this has been too great for the underlying material. Either a portion or all of the foundation may be removed and the structure supported by direct supports until the new and permanent foundation is fully completed and built in close and full contact with the underside of the base of the structure.

Such work is attended always with more or less risk of causing damage to the structure. With intelligent plans, and proper skill and care in the execution, the largest and heaviest structures can be underpinned with safety.

DESIGN.

The loads carried by the columns of tall buildings are of two kinds, each requiring a separate discussion. First in order is the dead load consisting of the weight of the structure itself and including all permanent built in machinery, safes, etc. The live load is much less certain than the dead load and cannot be as accurately estimated. It consists of all moving loads, the people occupying the building, machinery, and wind. The floors of the buildings are designed to carry a certain definite live load according to the type or clas in which the building comes. This load, however, has a definite minimum fixed by the Chicago Building Code, which includes any direct live load which may come in contact with the floor as people, merchandise, and fixtures. The wind load in large buildings in Chicago is fixed at 20 pounds per square foot of exposed surface. That this is a very uncertain quantity may be readily seen from the fact that no tall building has all of its exterior walls exposed, and furthermore, an ordinance provides that the moment due to wind load shall never exceed 75% of the moment due to the dead load of the structure.

Knowing the live load which the floors of the structure will carry, a preliminary design of the floor may be made. The type of floor, whether it be hollow tile arch construction or a reinforced concrete slab, will first be decided. The arch or slab is next designed for the span given, and the dead load and live load carried by the floor beam is at once known, hence the beams may be designed. Following this in order comes the floor

girders, which in turn transmit their load to the columns. Since the load on the column at each floor is determined in this way, the column section may be designed. The load which the column carries to its base is now easily determined by summing up the loads at each floor.

Computations of the loads and the determination of the size of the caissons are shown on plates VII and VIII. Plate VII is the design of Caisson No. 21 in the Lytton Building, Chicago, Illinois. The dead load per square foot is determined from the floor system and the permanent partitions and is shown in column two of the table. Column three gives the reduced live load per square foot according to the Building Code, the fact that the load is high below the seventh floor is due to the change in type of building. The first seven floors are used for Department store purposes and the remaining upper floors are used for offices. Column four gives the total load per square foot on each floor and column five the floor area carried by column No. 21 at each floor. Column six gives the total load per floor in thousands of pounds, and column seven gives the total load at each floor. The total load is found to be 2,570,700 lbs., and using 40,000 lbs. per square foot allowable bearing, as Mr. E.C. Shankland recommends in an article written for the Technograph, the size of the caisson is found to be 9.06' or 9'-1" in diameter. This size checks within 1" of the caisson as actually built on the Lytton Building.

Plate VIII shows the calculation for caisson No. 3 of the same building. In this plate columns three, four, and five show

PLATE VII

DESIGN OF CAISSON #3

LYTTON BUILDING — CHICAGO, ILL.

SCHEDULE — COLUMN #3								
Story	Story Height	D. L. + L. L. per sq. ft.	Floor Area sq. ft.	Total Floor Load	Total Wall Load	Vert. Incr. at Floor due to Wind	Increment	Total Load
Pent House								
Roof	32'-0"	225.0	398	89.5			89.5	89.5
18th	12'-9½"	220.0	do	87.5	157.2	1.9	244.7	336.1
17th	12'-9½"	217.5	do	86.5	31.5	3.8	118.0	456.0
16th	12'-9½"	215.0	do	85.5	30.0	6.2	115.5	573.9
15th	12'-9½"	212.5	do	84.5	30.0	9.7	114.5	691.9
14th	12'-9½"	210.0	do	84.5	30.0	13.1	113.5	808.8
13th	13'-9½"	207.5	do	84.5	30.0	17.3	112.5	925.5
12th	13'-9½"	205.0	do	81.5	32.8	23.7	114.3	1046.2
11th	13'-9½"	202.5	do	81.5	32.8	28.7	113.3	1164.0
10th	13'-9½"	200.0	do	79.5	32.8	35.5	112.3	1283.6
9th	13'-9½"	200.0	do	79.5	32.8	43.0	112.3	1403.4
8th	13'-9½"	200.0	do	78.5	37.6	51.0	117.1	1528.5
7th	14'-9½"	200.0	do	79.5	39.6	60.0	119.6	1657.1
6th	14'-9½"	260.0	do	103.5	43.0	70.5	146.5	1813.8
5th	14'-9½"	255.0	do	101.5	43.0	81.6	144.5	1969.4
4th	17'-0"	250.0	do	99.5	43.0	93.5	142.5	2123.8
3th	15'-9½"	245.0	do	97.5	86.0	122.5	183.5	2336.5
2nd	16'-9½"	240.0	do	95.5	79.8	140.0	175.3	2529.1
1st	20'-6"	235.0	do	93.5	85.0	161.2	178.5	2828.8
Basement	16'-2½"	275.0	do	109.5	104.3	180.0	213.8	3061.4
1st. Sub-Base.	15'-0"	230.0	do	91.5	142.0	197.0	233.5	3311.9
2nd. Sub-Base.	12'-0"	225.0	do	89.5	131.0	212.2	220.5	3547.6
						Total Load 3,547,600#		

Allowable Bearing 40,000#/□'

$$d^2 = \frac{4 \times 3{,}547{,}600}{40{,}000 \times 3.1416} = 112.8$$

$d = 10.6'$

∴ Use 10'-8" Caisson

the sum of the dead and reduced live load per square foot, the floor area carried by column No. 3, and the total floor load, respectively. Column five the shows the wall load at each floor, and column six the vertical increment at the floor due to the wind which was calculated with a wind load of 20 lbs. per square foot and under the assumption that the vertical increment resisting the wind moment was all taken up by the outside row of columns. The total load was found to be 3,547,600 lbs., which necessitates a caisson 10.60 feet or 10'-8" in diameter.

In the smaller buildings it is often desirable to use a caisson of uniform size for the sake of economy. However, such conditions are almost impossible to attain where there is much special construction. The loads will be determined to a great extent by the location of the columns.

Special loads such as are caused by heavy generating and operating, or manufacturing machinery require careful calculation. The location and arrangement of all such machinery is decided upon by the Mechanical Engineer. The members carrying such apparatus must be designed for high impact stresses, and are consequently very heavy, especially when such machinery is located on floors where the depth is limited, in which case the sections must be made uneconomically heavy to withstand the strain to which they are put. Nearly all large buildings are provided with heavy fireproof vaults for the safekeeping of records, etc. These vaults are placed above the first floor for convenience and cause enormous dead loads. In the case of the Continental and Commercial National Bank Building a certain

PLATE VIII

DESIGN OF CAISSON #21
LYTTON. BUILDING ~ CHICAGO, ILL.

SCHEDULE COLUMN #21

Story	D.L.	Reduced L.L.	D.L. + L.L.	Area in Sq. Ft.	Load per Story	Total Load
Roof						
18th	175.0	50.0	225.0	543	122.2	122.2
17th	do	45.0	220.0	do	119.7	241.9
16th	do	42.5	217.5	do	118.4	360.3
15th	do	40.0	215.0	do	117.0	477.3
14th	do	37.5	212.5	do	115.5	592.8
13th	do	35.0	210.0	do	114.0	706.8
12th	do	32.5	207.5	do	112.6	819.4
11th	do	30.0	205.0	do	111.2	930.6
10th	do	27.5	202.5	do	110.0	1040.6
9th	do	25.0	200.0	do	108.8	1149.4
8th	do	25.0	200.0	do	108.8	1258.2
7th	do	25.0	200.0	do	108.8	1367.0
6th	do	85.0	260.0	do	141.2	1508.2
5th	do	80.0	255.0	do	138.6	1646.8
4th	do	75.0	250.0	do	136.0	1782.8
3rd	do	70.0	245.0	do	133.1	1915.9
2nd	do	65.0	240.0	do	130.3	2046.2
1st	do	60.0	235.0	do	127.8	2174.0
Basement	do	100.0	275.0	do	149.4	2323.4
1st Sub-Base	do	55.0	230.0	do	125.0	2448.4
2nd Sub-Base	do	50.0	225.0	do	122.3	2570.7
				Total Load		2,570,700#

Allowable Bearing 40,000 #/□'

$$d^2 = \frac{4 \times 2,570,700}{40,000 \times 3.1416} = 82$$

$$d = 9.06'$$

$\therefore$ Use 9'-1" Caisson

column weighs 45 tons, this is however, exceptionally heavy construction for Chicago.

The question of bearing power of soils is one which has always given architects and engineers no end of trouble. This has been especially true in the business center of the city of Chicago which was originally a swamp a few feet above the Chicago river and 14 feet below the present grade level. The solution of a type of foundation for the modern tall building seems to be the caisson which extends to hardpan or bedrock. Where the loads are not enormously large, and where there is little danger that the the adjoining property owner will ever exceed them in depth, these caissons are permitted to rest on hardpan. The term "Hardpan" itself has a good many different meanings among prominent designers, some taking it to be a tough surface clay while others only consider as being true hardpan a soil almost as hard as rock located at depths from 60 to 100 feet below grade. However a generally accepted definition of true hardpan is that it is a very hard, dry, blue clay, mixed with small pebbles, so hard that a scratch cannot be made upon it with the fingernail, nor could a lump be crushed under the weight of a man.

During the present year, various Architects and Engineers of Chicago in cooperation with the Building Department of the City, carried on various tests to determine what safe loads might be placed on soil at considerable depths below the surface. On the hardpan tested it was necessary for a good stout digger to swing his pick with great energy in order to drive it into the

hardpan 1/2".

The method used in testing was to lower a heavy timber loading platform to the bottom of the shaft. A plan and elevation of this platform are shown on plate IX. A braced 12" x 12" post 4'-0" in length having a steel plate 12" x 12" x 1-1/2" on the underside transmitted the pressure from the heavy platform of 3" matched boards to the soil. A hook securely fastened to the platform provided a means of fastening a steel tape to the apparatus, this tape extended to the surface and was sufficiently counterweighted to give a tense line so that all readings were accurate. The results of these hardpan tests together with several others are given in the table on plate X.

In testing the bearing power of soils the question arises as to the relative bearing power of small areas compared with large ones. Although the areas of various footings vary considerably in the same building, it is the usual thing to use the same unit pressure on both small and large footings. This question came up about six years ago wheh Mr. Wm. Artingstall was chief of subway engineers of Chicago, in the underpinning of the Van Buren Street Railway Tunnel for the Chicago Union Traction Co. The soil in question was a hard blue clay , it could be grubbed, and yet it was not too hard to dig with a clay knife.

A hole was cut in the bottom of the old tunnel, and a place leveled off in the clay for the steel bearing plate. A drum was then placed on this bearing plate extending to the bottom flange of the girder above, the jackscrew was provided with a lever on which the pull was obtained by means of a block and

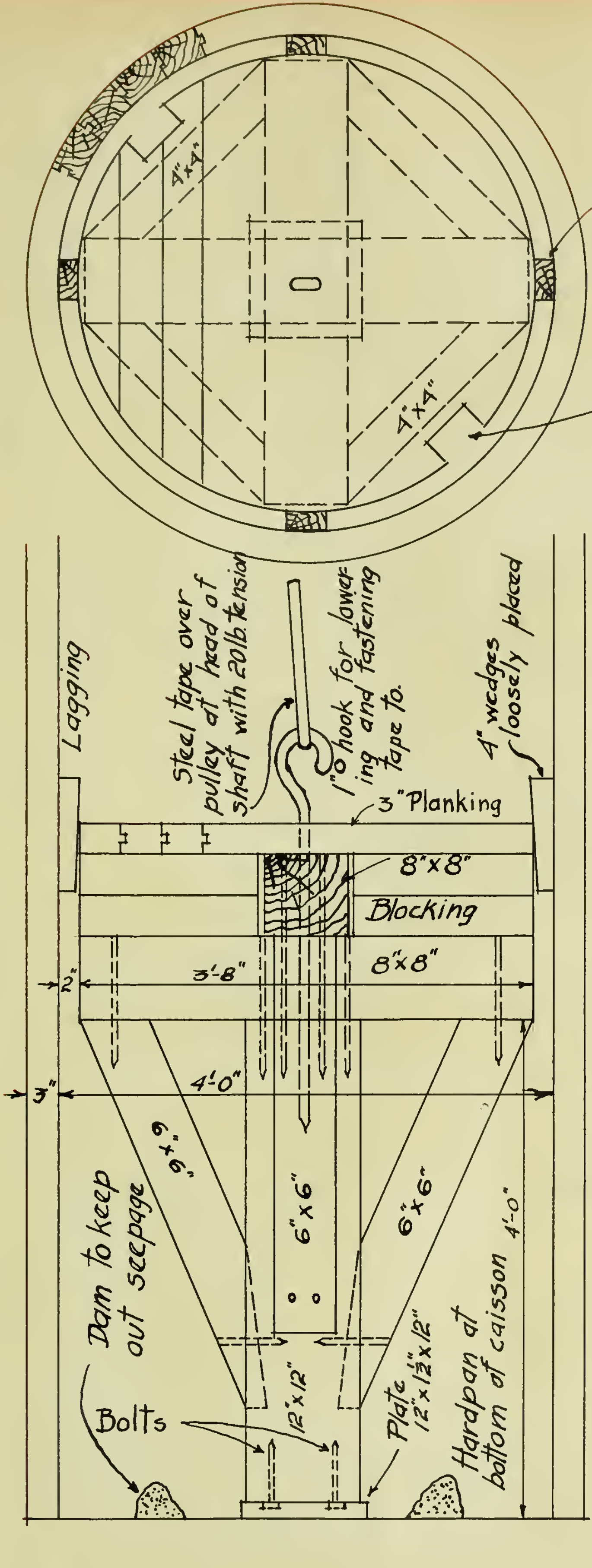


PLATE IX

PLAN AND ELEVATION OF THE LOADING PLATFORM USED IN MEASURING THE BEARING VALUES OF SOILS.

SCALE 3/4" = 1'-0"

HARDPAN AND OTHER SOIL TESTS   PLATE X

BUILDING	SOIL	LOAD IN LBS/SQ.FT.	TOTAL TIME IN HOURS.	SETTLEMENT IN INCHES	REMARKS
NEW COOK COUNTY HOSPITAL HARRISON ST. BET. WOOD & LINCOLN	HARDPAN	4100	0	0	CAISSON 4'-3" DIAMETER 51' BELOW CITY DATUM. HARDPAN 15'-0" THICK.
		10 900	6	0	
		24 200	13	0	
		24 200	58	3/16	
MARSHALL FIELD EST BLDG. WABASH & S. WATER	HARDPAN	10 600	0	0	66'-0" BELOW DATUM
		24 200	25	0	
		24 200	95	7/16	
BUTLER BROS. RANDOLPH, CANAL & LAKE STS.	HARDPAN	2000	0	0	70'-0" BELOW DATUM 4'-6" DIAMETER. DRY AT ALL TIMES.
		30 000	16	0	
		30 000	76	3/16	
SEARS, ROEBUCK & CO. HARVARD AND CENTRAL PARK AVE.	STIFF BLUE CLAY	3000	0	0	10'-0" BELOW DATUM MEASUREMENT OF SETTLEMENT OBTAINED BY MEANS OF AN ENGINEER'S LEVEL AND ROD.
		6500	1	0	
		15 200	3	0	
		24 100	4	5/8	
		"	12	1 13/16	
		"	43	2 5/16	
		"	65	2 11/16	
		"	114	4"	
FEDERAL BLDG.	MOIST BLUE CLAY	1000	Load changed	3/32 3/16	ELEVATION - CITY DATUM. DISTANCE BET. TESTING POINTS 150'-0". BEARING AREA 4 SQ.FT. SETTLEMENT TAKEN BY WYE LEVEL AND ROD.
		2000	after settling	13/64 1/2	
		3000	had ceased	25/64 1 3/16	
		4000	in each case.	49/64 1 3/4	
		"	one hr.	1 13/64 1 7/8	
		"	Next day	---- 1 7/8	
		"	Two hrs.	1 21/32 ----	
		"	Four wks.	2 9/32 ----	
		"	Next day	2 19/32 ----	

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tackle, operated by two stout laborers. The pull on the lever was registered directly by means of a dynamometer connected to the lever arm. Several tests were made with bearing plates of different sizes and in different locations but on the same character of soil. In each case the load that would produce the same amount of settlement was obtained, the results are as follows:-

Size of Bearing, inches.	Load per square foot, pounds.
4 x 4	16,000
6 x 6	24,000
8 x 8	44,000
8 x 12	64,000
12 x 14	98,000

From the foregoing tests some idea may be obtained as to the variation in bearing power of small areas as compared with larger areas. The question which seems to be the logical outcome of this great variation is, "What should the standard area for testing soils be, at least in the field?" A large number of tests have been made in which the area used was one square foot. It seems that there is a necessity for adopting some such standard as this for the purposes of comparison to correspond with the testing standards used in making other engineering tests.

Some criticism is made of the practise of permitting caissons to rest on hardpan. It is claimed that occasionally underlying this strata of hard clay there are beds of plastic clay, and sometimes quicksand before bed rock is encountered. These wells have been sunk through soft material and large quantities of material have been pumped from surrounding

property. The danger in doing this has been evidenced by the lateral movement in some older buildings as far as 100 feet distant from the nearest well. In one case a city street was so seriously cracked as to require expensive repairs because of the material taken out in the excavation of a deep caisson. It seems that an engineer who permits his caissons to rest on hardpan instead of going a few feet farther down to bed rock, particularly in a city like Chicago, which is constantly changing and growing, is showing a lack of foresight in protecting and safeguarding the future interests of the owner.

This squeezing out and movement of the softer or plastic soil under heavily loaded areas is no mere theory as there are many examples of settled walls about the loop where old buildings adjoin the new. A late prominent engineer of Chicago who had been identified with the dredging operations of the Chicago River is responsible for the statement that the river bottom rises two or three feet every four or five years. This rise is not due to the silting up of the river as the water is practically pure as it enters the river. It was this engineer's belief that this rise was due to the fact that the river bottom offers the least resistance to the enormous pressure of the large buildings on both sides of the river, and that the soil is squeezed up into the river bottom.

In a discussion on soil foundations and conditions in Chicago, Mr. F.E.Davidson says that he has loaded hard clay to as much as 7,500 lbs. per square foot, and the structure after five years has shown no appreciable settlement. Any foundation

constructed on clay will settle. The problem is to so design the building that the settlement will be uniform. There is danger in designing foundations for any important structure, unless provision is made for the redesigning of foundations after the actual excavation has been started to provide for changes in the character of the soil.

In order to provide for uniform settlement in structures subject to both live and dead loads, the proper distribution of the assumed live loads is as vital and important as the selection.of the proper unit stresses. Great care must be exercised in determining what unit stresses to allow for columns carrying a large percent of live load where outside piers have a large percent of dead load so that the settlement, if there is any, will be uniform. Three important features to be considered in the design of foundation work are: 1, the dead weight of the structure; 2, the live loads; 3, impact loading such as the vibration of heavy machinery or the impact effect of a large number of elevators.

Mr. Wm. Artingstall says there is no question as to the movement of the soil. When any large excavation is begun there will always be difficulty on account of the earth rising. The Chicago River was first dredged in 1856 and since that time at five year intervals it has been necessary to remove two to three feet of virgin clay to maintain the original dredged depth.

In building the west approach of the Washington Street tunnel the foundations of the Chicago and Northwestern Railway terminal were encountered, these were piles driven 50 to 60 feet

datum. The columns settled about 2-1/2" and moved laterally about 2 inches.

Mr. T.L. Condron believes that the practise of digging deep foundations in Chicago and pumping out unlimited amounts of earth will eventually require legislation. This disturbs the surrounding soil and accounts, in a large measure, for the settlement and lateral movement of neighboring buildings. A good many of the buildings have hardpan foundations and they will carry an indefinite amount of load until the material (silt or quicksand) is pumped from beneath the hardpan.

In testing the soil for a nine story warehouse to be erected at Hubbard and West Streets, New York, it was found that the following loads and settlements were obtained by exceedingly careful testing:

Load in tons per square foot	Settlement in inches
4	3/32
6	3/16
8	15/32
12	1-3/32
16	1-20/32
20	2-10/32
24	3-1/32
28	3-11/32

The above weights all represent the net load on the platform and should in each case be increased by one ton. The test was commenced on March 21 st. until April 13 th. The permissible

load as given by the Building Department of New York in this case was 12 tons per square foot, allowing a factor of safety of a little more than two. There is no fixed factor of safety for soil tests, each engineer after studying all the conditions with great care, designs for loads which he in his judgement deems safe. The hardpan on the Butler Bros. Warehouse as shown in the table Plate X was loaded to 30,000 lbs. per square foot for a period of 76 hours, showing a deflection of 3/16" at the end of that time. The unit load used in designing that building was 8,000 lbs. per square foot, although a load of 12,000 lbs. would be commonly used. Where the wells extend to bed rock which has been tested as a true stratum of thick limestone there is no question as to its bearing power, the allowable stress for designing is then determined by the compressive strength of the concrete. The Chicago Building Ordinance for 1912 allows the following stresses in pounds per square inch:

First-class granite masonry, Portland cement mortar,	600.
" " lime and sandstone masonry Port. Cem. "	400.
Portland cement concrete 1:2:4 mixture machine mixed	400.
" " " " " hand "	350.
" " " 1:2-1/2:5 machine "	350.
" " " " " hand "	300.

A typical example may be taken of a caisson on the Continental and Commercial National Bank Building. The wells rest on bed rock and are made of 1:2:4 concrete which from the above table will stand 400 pounds per square inch and are topped with first class granite concrete which will stand 600 lbs. per square

inch in compression. Subtracting the dead weight of the concrete from the allowable stress, 350 lbs. per square inch will be a good compression to allow in getting the area between the top of the caisson and the column. A unit load of 350 lbs. per square inch corresponds to a load of a little more than 50,000 lbs. per square foot. This is a very high bearing value when one considers that a caisson of this type only 6'-3" in diameter would be capable of carrying the dead load for the largest column in the Woolworth Building in New York City.

The building Ordinance gives no unit allowable load on these deep soils but requires tests to be made and unit stresses are then agreed upon between the engineer and the commissioner of buildings based on the actual tests.

After the loads have been estimated, the soil tested and the bearing values determined it must be decided whether the caisson will be of the hard pan or bed rock type. The location of the building has a great deal to do with the decision because east of State Street and along the river it is very hard to sink caissons to rock without the use of air. The allowable bearing values for hardpan taken by most engineers in Chicago is 12,000 pounds per square foot, the true bearing value can be determined by tests but there is no set factor of safety, different engineers using different values.

Whether the bed rock or hard pan caisson should be used is left entirely to the engineer, but it seems that the best plan is to go down to rock as the nature of the soil under the hardpan is never known, in places there is a strata of very soft,

wet clay or quicksand and the hardpan caissons will settle when a building next to it goes down to solid rock.

The body of the caisson as built in Chicago is of a 1:2:4 mixture, which is good for allowable pressures of from 400 to 500 pounds per square inch. Such a stress is a very safe one throughout the concrete, but where the load is received from the column it is essential to provide better materials which will be more uniform in character and better able to stand higher compression. The usual method of handling this part of the caisson is to provide a "capping" of a different mixture of cement and aggregate to a depth of about 18". Various mixtures have been used with success and no doubt many untried combinations may be used with equal success. In one case sufficient bearing strength was provided by using an aggregate of wrought nails with an equal part of Portland cement, this worked very well and the nails were in no danger of corrosion because of the protection afforded by the cement covering. A more common mixture is the one of coarse granite screenings with an equal part of Portland cement. The essential feature is careful mixing to prevent the presence of all voids. As the concrete mixture is brought to the top great care is exercised in obtaining the proper height, wooden screeds are placed in the wet mixture, these being set to the proper level. The grillage beams are set on these wooden screeds and very carefully grouted with a mixture of one part of cement and one of sand. The grouting acts as a proptection to the steel and also provides a more uniform bearing for the beams should there be any irregularity in the

finished capping.

The subject of column bases in the design of tall buildings is one which does not seem to receive much attention of the designer for several reasons. In the first place the cost of the base is a comparatively small one so that it does not pay to have a high-salaried engineer work a long time trying to save a small amount of metal. Secondly, the mathematician has been unable to furnish a solution of the stresses in flat plates of which the column base is an example. In Bulletin No. 35 University of Illinois Experiment Station, Dr. Ricker takes up a study of flat base and bearing plates, in which the design of the plate is arrived at by determining the line of fracture. However, very little is known of the ordinary webbed base plate which has such common use in modern construction.

Where the base plates rest directly on masonry the area of the plate which comes in direct contact with masonry is of course determined by the bearing power of the material, the metal is usually made heavy and the sides sloped at about 60 degrees. Where the buildings are large and column loads correspondingly great the bearing area would become excessively large. When such is the case, the base transfers the load from the column to the caisson by means of a set or several sets of steel grillage beams properly designed. An example of this is shown in Plate No. IV representing a typical column base of the Lytton Building in Chicago. Mr. E.W.Stern, a consulting engineer of New York City, has made a study of column bases and suggests a type of I-beam grillage base to be used in preference to the cast iron

base and steel grillage. The grillage base is found to be cheaper and more reliable than the cast iron base. Many times the latter, even though carefully annealed and inspected before leaving the shop, will develop cracks when the structure is up several stories, necessitating their removal to be replaced by sound ones. The expense caused by replacing these bases is very large and gives room for a saving by avoiding such uncertain types of details. The grillage base is easier to set properly and causes less difficulty in grouting. The stresses can be readily calculated by employing the conventional method of analysis for shear, crimping, and bending, which is accurate enough for all practical purposes.

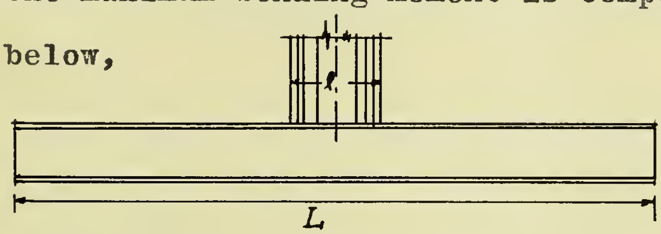
Shallow beams with heavy webs are to be preferred, avoiding the necessity of reinforcing the web. However, Mr. Stern always uses stiffeners ground to fit in the upper tier of beams whether or not the calculations show them to be required.

In building these grillage bases, the beams are built up complete in the shop, and each tier of beams is bolted together ready for erection in one piece. Pipe separators should be used plentifully and in the top layer they should be spaced not over 6" vertically and 8" horizontally. After setting, the base is grouted, all bases being filled with 1:2 Portland cement mortar.

By comparing plates No. V and VI with plate No. IV illustrating the two types of base and grillage, the difference in cost is at once apparent. The amount of steel grillage in both is about the same, the concrete protection for the cast base is in

excess of that for the grillage base whereas the shop work on the grillage type is a little larger and greater care must be exercised in setting. The advantages derived by safety and rational design tend to the adoption of the grillage base.

The calculation of the number and size of grillage beams to distribute the loads may be made in the following manner:- A number of beams, preferably five but sometimes six, in the lower set of beams. In a particular instance there will be a space limitation which will determine the length of beams to be used. Having this length and the load, the number of beams based upon crimping of the webs may be found from the tables in the Steel Handbooks such as Cambria, page 74 in the 1909 edition. The next step is to determine whether or not the grillage beams are safe in bending, the maximum bending moment is computed as shown by the diagram below,



$M=1/8(L-l)wL$ foot lbs.

In which, w=pressure in lbs. per lineal foot.

l=width of column in feet.

L=length of beam in feet.

This equation gives the same result as though the moment were taken as twice the moment of each cantilever from edge of the column to the end of the beam. The beams should be spaced about 9" center to center; however if the flanges are so wide that they do not allow at least 2" between to permit grouting, they should be spaced farther apart. Where the spaces are

thoroughly grouted as they should be, pipe separators are s sufficient since they simply hold the beams true until the grout has set. The pressure between the steel and concrete should not exceed 500 pounds per square inch.

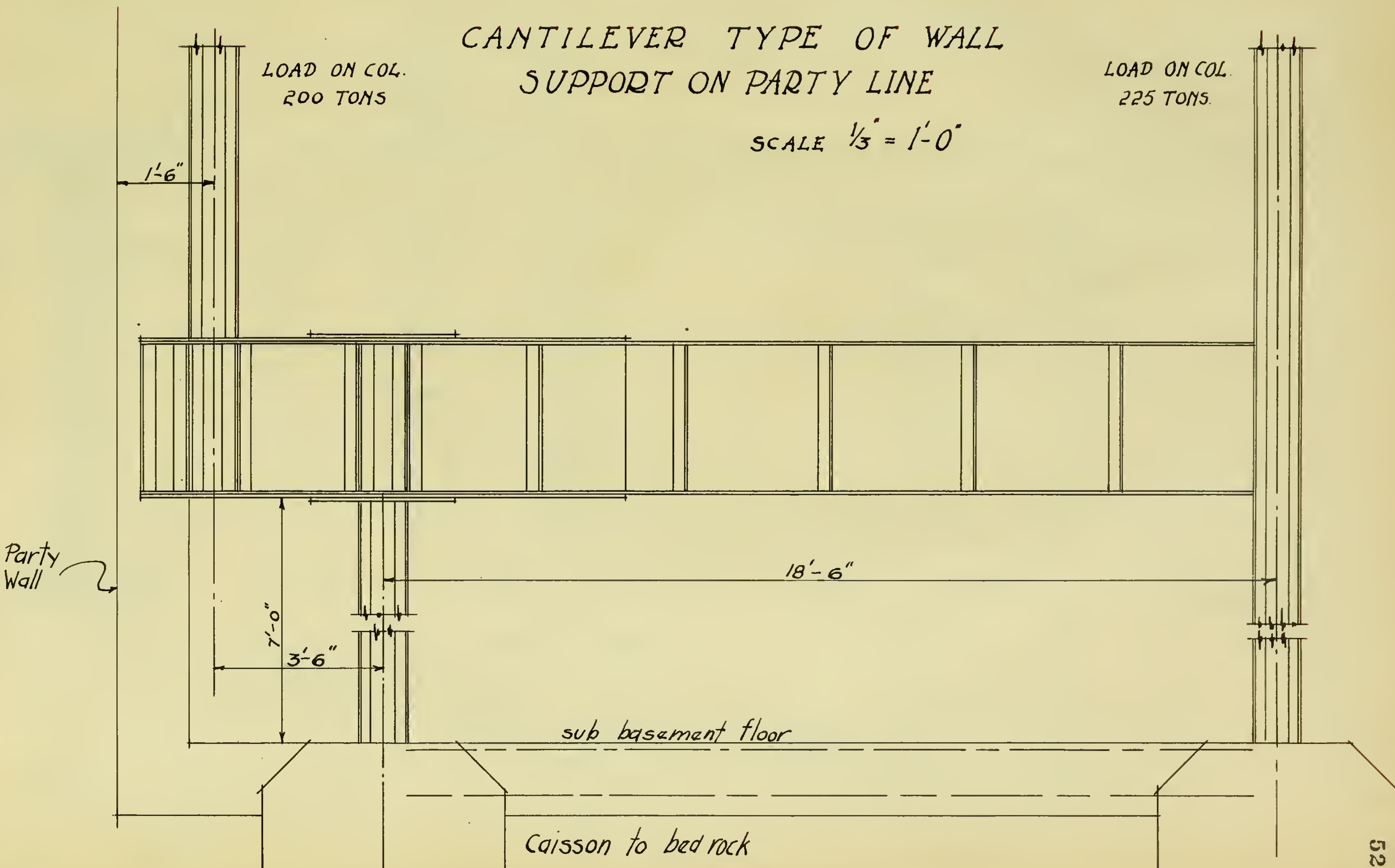
The method of distributing the column load across the grillage may be effected by the use of a cast base, wing plates, or a billet plate. Many formulas have been advanced for determining the thickness of these plates which depends upon the pressure and protection from the column to the edge of the plate. There are as many of these formulae as there are prominent engineers and no two of them agree. Kidder gives the thickness of plate in inches equal to $\sqrt{\frac{w \times P^2}{1600}}$ in which w = the load on the plate divided by its area in square inches, and P = the projection of the edge of the plate beyond the post or column.

Many skyscrapers are built in the middle of a city block with party walls on either side. In Chicago these party walls are an old building with floating foundations. During the erection of a heavier structure next to it, these walls must be jacked up to prevent serious settlement. As it is impossible for the caisson to be built directly under the new wall, owing to the fact that it would then extend into the neighboring property, it is necessary to set the caisson back five or six feet from the party line, depending upon its diameter which of course is determined by the load it carries. The wall is then supported on a series of overhanging plate girders extending to the first interior caisson. The cantilever usually comes in the

floor just above the lowest sub-basement and is supported on short steel columns as shown in plate No. XI. These lower floors contain the mechanical plant of the building and it is therefor necessary to provide sufficient head room for the apparatus. Hence the design of the plate girder is one which requires a limited depth, with enormous shear at the support nearest the overhang, where the maximum moment which is negative occurs. This usually requires a box section to provide sufficient area in the web, from one to two cover plates over the support and heavy stiffeners closely spaced. The usual methods of plate girder design may be employed with regard to moment and shear. From these, the thickness of web, and the area of flange together with rivet spacing may be obtained. As the moment diminishes, the cover plates may be cut off one foot beyond the point where their area is no longercrequired to resist the bending moment. It is also permissible to cut off web plates and thereby effect an economy in the design where they are no longer needed to resist stress. The stiffeners should be milled to bear tight against the flange of the girder, and wherever necessary they should be crimped. The number of stiffeners under the column is determined by allowing a compression of 20,000 lbs. per square inch on the outstanding leg of the angle. They should never be spaced farther apart than the depth of the girder, and preferably closer than the depth.

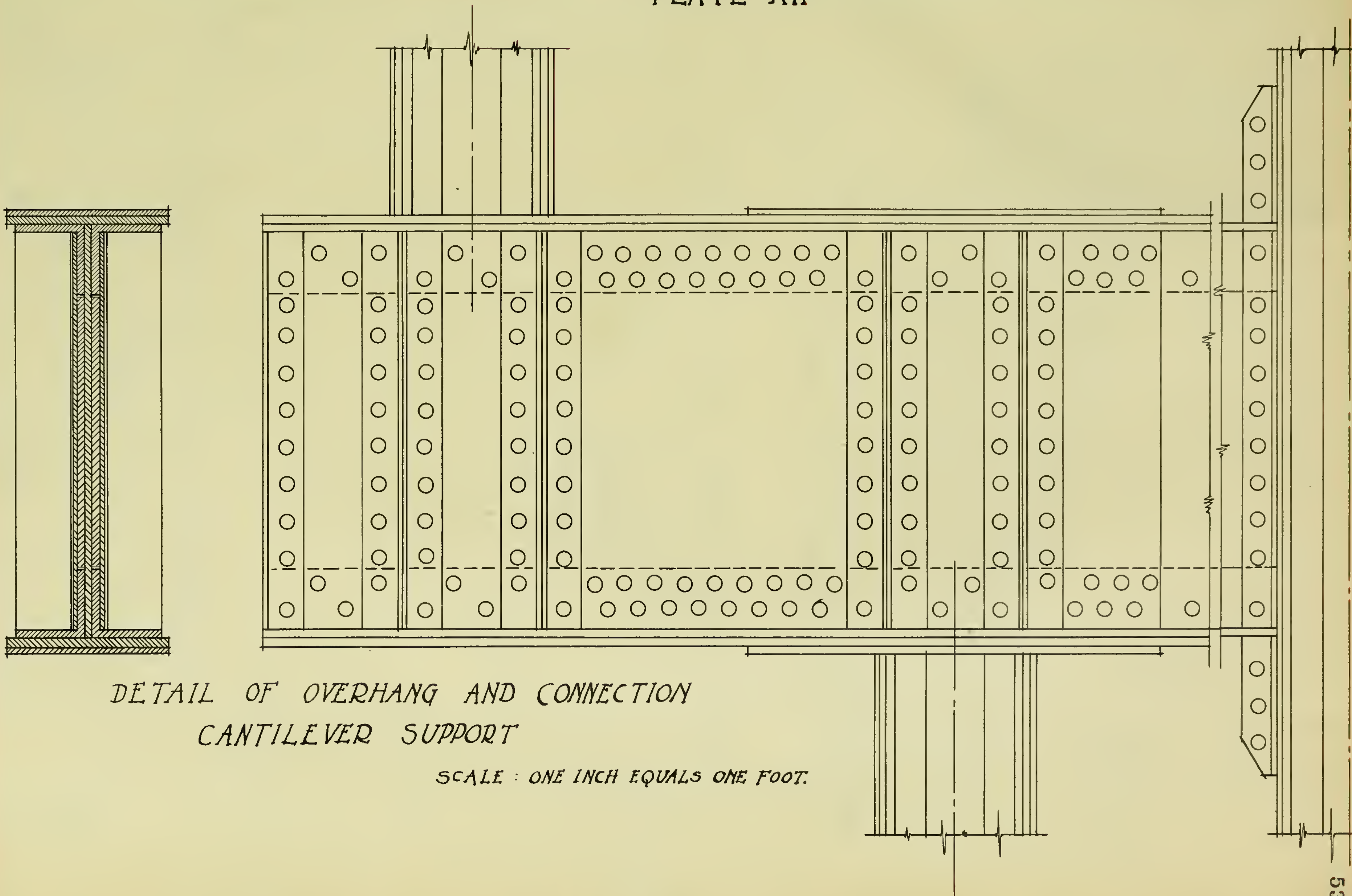
Plates XI and XII show large size details of such a plate girder, and shear and moment diagrams for determining the thickness and length of cover plates respectively.

PLATE XI



CANTILEVER TYPE OF WALL
SUPPORT ON PARTY LINE
SCALE 1/3" = 1'-0"
LOAD ON COL.
200 TONS
LOAD ON COL.
225 TONS.
1'-6"
18'-6"
7'-0"
3'-6"
Party Wall
sub basement floor
Caisson to bed rock

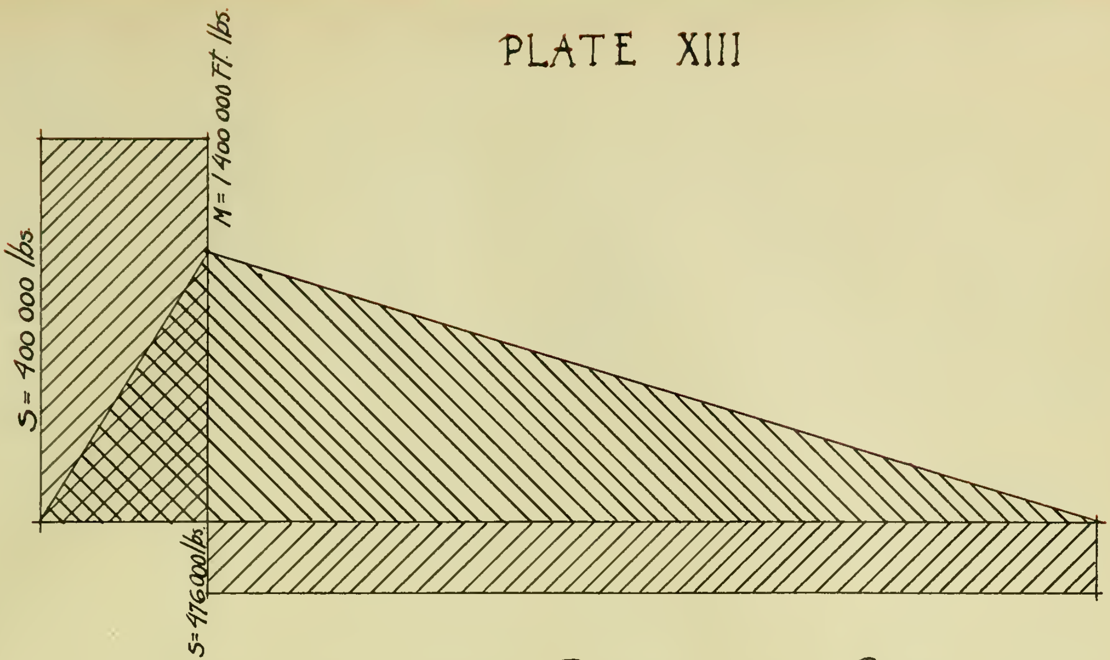
PLATE XII



DETAIL OF OVERHANG AND CONNECTION
CANTILEVER SUPPORT

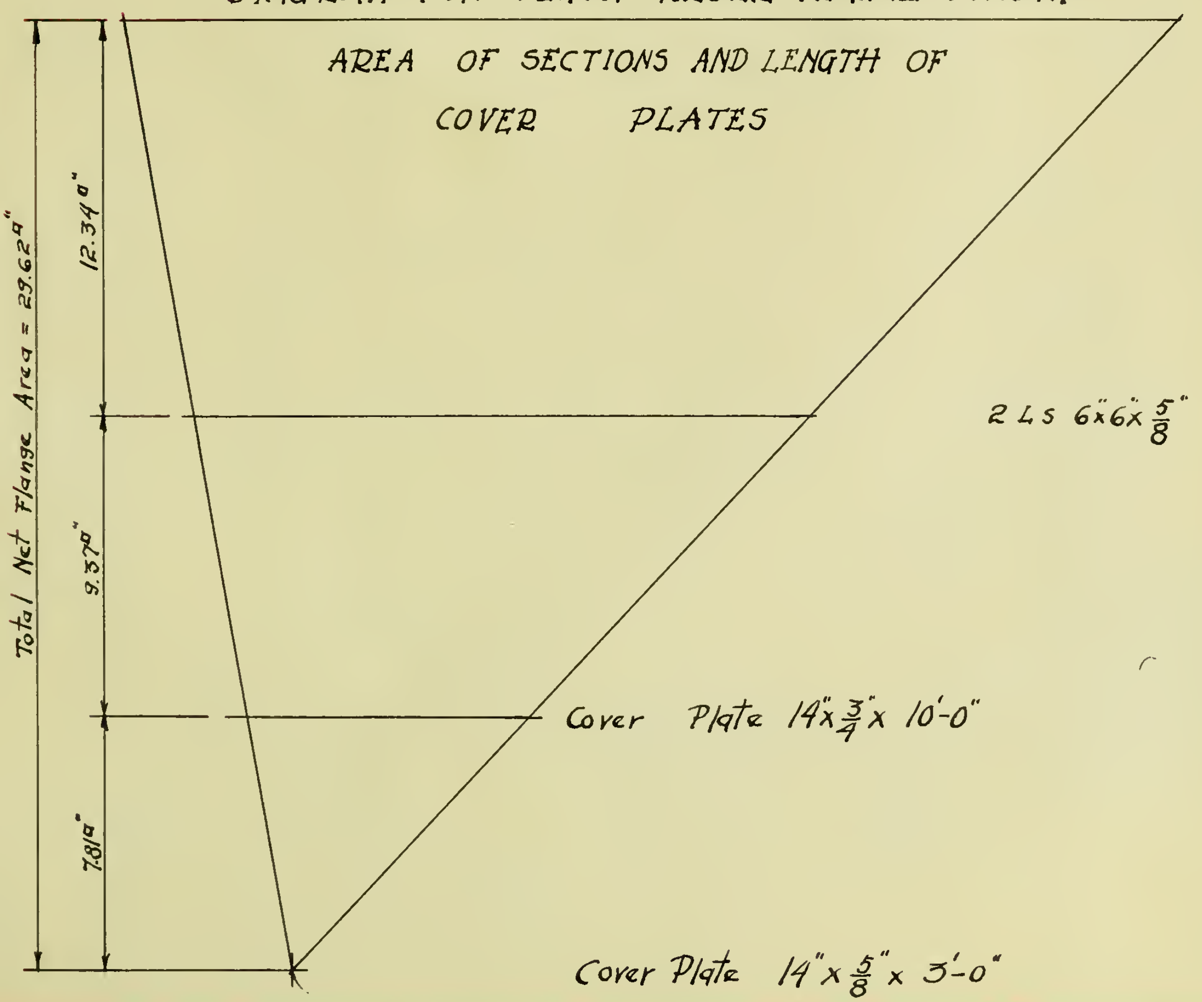
SCALE : ONE INCH EQUALS ONE FOOT.

PLATE XIII



SHEAR AND MOMENT DIAGRAMS FOR PLATE GIRDER DESIGN BY GRAPHICAL METHOD

DIAGRAM FOR PLATE GIRDER FLANGE DESIGN



Where such large stresses are encountered the greatest of care should be exercised to provide against all contingencies The girder should not be too deep for its width, and should be braced laterally against crippling. One way of providing this lateral bracing is to fasten the girder to the inner column as shown in the detail on plate No. XII.

ESTIMATING.

The excavation is figured in cubic yards, using the diameter of the caisson plus the lagging. This will range in cost from $5.50 to $6.50 per cubic yard according to the size of the well. The bell is figured as the diameter times the height. Wooden lagging costs $25.00 per thousand feet. Add $20.00 to $30.00 for breaking top, and $20.00 for ventilation. Rings cost $50.00 per ton, and 3¢ to 3-1/2¢ per pound is allowed for rings left in place. The labor for concreting the wells costs from $1.25 to $1.55 per cubic yard, and the cost of the concrete for various mixtures can be found on the table of unit costs on Plate No. XIV. This table was suggested by Mr. North, head estimator for Wells Bros. Contractors Chicago.

General excavation costs from $1.25 to $1.75 per cubic yard, and sub-basement work from $2.40 to $3.00, and deep tre trenches, $5.50 to $6.00. It costs 85¢ per cubic yard to haul general excavation by wagon, and 90¢ per cubic yard to haul sub-basement excavation through the Illinois Tunnel. Direct drumming under an adjoining building costs $12.00 to $15.00 per lineal foot and needle shoring costs $15.00 to $20.00 per lineal foot. The cost of the caisson complete at the present time is about $14.00 to $15.00 per cubic yard, or only half as much as the cost when the first caissons were built in Chicago.

Insurance liability rates are high on account of the great risks under which the men work. The rates for diggers and nigger head men is 10% of their payroll, and the remainder of the men on the pay roll at 3-1/2%. To the total figures obtained from

TABLE OF COSTS OF A CUBIC YARD OF CONCRETE FOR VARIOUS MIXTURES BASED ON 40% VOIDS AND 1 BBL.=4 CU. FT.

PLATE XIV

	Unit Costs	1:1½:2	1:2:4	1:2½:5	1:3:5	1:3:6	1:3:7
cement Sand Gravel	.70	1.56 .34 .46	1.01 .30 .85	.83 .31 .61	.78 .34 .57	.70 .32 .63	.64 .29 .67
C S G	.75	1.67 .37 .50	1.08 .32 .64	.89 .33 .50	.83 .37 .62	.76 .34 .68	.69 .31 .71
C. S. G.	.80	1.78 .39 .53	1.15 .34 .68	.95 .35 .54	.89 .39 .66	.81 .36 .72	.74 .33 .76
C. S. G.	.85	1.89 .42 .56	1.22 .37 .72	1.00 .37 .57	.94 .42 .70	.86 .38 .77	.78 .35 .81
C. S. G.	.90	2.00 .44 .59	1.30 .39 .77	1.06 .40 .60	1.00 .44 .74	.91 .41 .81	.83 .37 .86
C. S. G.	.95	2.11 .47 .63	1.37 .41 .81	1.12 .42 .64	1.05 .47 .78	.96 .43 .86	.87 .39 .90
C. S. G.	1.00	2.22 .49 .66	1.44 .43 .85	1.18 .44 .67	1.11 .49 .82	1.01 .45 .90	.92 .41 .95
C. S. G.	1.05	2.33 .51 .69	1.51 .45 .89	1.24 .46 .70	1.17 .52 .86	1.06 .47 .95	.97 .43 1.00
C. S. G.	1.10	2.44 .54 .73	1.59 .47 .94	1.30 .48 .74	1.22 .54 .90	1.11 .50 .99	1.01 .45 1.05
C. S. G.	1.15	2.55 .56 .76	1.66 .50 .98	1.36 .51 .77	1.28 .56 .94	1.16 .52 1.04	1.06 .47 1.09
C. S. G.	1.20	2.66 .59 .79	1.73 .52 1.02	1.42 .53 .80	1.33 .58 .99	1.21 .54 1.08	1.10 .49 1.14
C. S. G.	1.25	2.77 .61 .83	1.80 .54 1.06	1.48 .55 .84	1.39 .61 1.03	1.26 .56 1.13	1.15 .51 1.19
C. S. G.	1.30	2.88 .64 .86	1.87 .56 1.10	1.53 .57 .87	1.44 .64 1.07	1.31 .58 1.17	1.20 .53 1.24
C. S. G.	1.35	3.00 .66 .89	1.97 .58 1.15	1.59 .59 .91	1.50 .66 1.11	1.36 .61 1.22	1.24 .55 1.28
C. S. G.	1.40	3.11 .69 .92	2.02 .60 1.19	1.65 .62 .94	1.55 .69 1.15	1.41 .63 1.26	1.29 .57 1.33
C. S. G.	1.45	3.22 .71 .96	2.09 .62 1.23	1.71 .64 .97	1.61 .71 1.19	1.46 .65 1.31	1.33 .59 1.38
C. S. G.	1.50	3.33 .74 .99	2.16 .65 1.28	1.77 .66 1.01	1.66 .73 1.23	1.51 .67 1.35	1.38 .61 1.42
C. S. G.	1.55	3.44 .76 1.02	2.23 .67 1.32	1.83 .68 1.04	1.72 .76 1.27	1.56 .70 1.40	1.42 .63 1.47
C. S. G.	1.60	3.55 .78 1.06	2.31 .69 1.36	1.89 .70 1.07	1.78 .78 1.31	1.62 .72 1.44	1.47 .66 1.52
C. S. G.	1.65	3.66 .81 1.09	2.38 .71 1.40	1.95 .73 1.11	1.83 .81 1.35	1.67 .74 1.49	1.52 .68 1.57
C. S. G.	1.70	3.77 .83 1.12	2.45 .73 1.45	2.00 .75 1.14	1.89 .83 1.39	1.72 .76 1.54	1.56 .70 1.62
C. S. G.	1.75	3.88 .86 1.16	2.52 .75 1.49	2.06 .77 1.17	1.94 .86 1.44	1.77 .79 1.58	1.61 .72 1.66

NOTE: – Unit costs are for one barrel of cement, one cubic yard of sand and of stone or gravel. Quantities from TAYLOR AND THOMPSON.

the above, should be added the overhead expenses and about 15 or 20 percent for profit. The reason for this seemingly high percentage of profit is that the work is most uncertain. A good many contractors and architects refuse to give an actual estimate of the cost of the caissons for a building. Better work and satisfaction are the result of the "cost plus a fixed sum" method of doing the job.

A general practise among the caisson contractors of the city of Chicago is to offer a bonus of a certain sum of money usually about $100.00 to the set of diggers that finish their well first. As this prize money is offered for every set of wells dug, it creates no ill feeling among the men, for if they do not win the first time, they have plenty of chance for the other prizes.

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Professor C.W.Malcolm Class Notes.

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CONTINENTAL AND COMMERCIAL NATIONAL BANK BUILDING. CHICAGO, ILLINOIS.